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| <b>1. REPORT DATE (DD-MM-YY)</b><br>20/12/02                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |             | <b>2. REPORT TYPE</b><br>Technical report |                                   | <b>3. DATES COVERED (From - To)</b>                   |                                                                    |
| <b>4. TITLE AND SUBTITLE</b><br>Instrumentation Facility for the Evaluation of Photonic and Optoelectronic Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                           |                                   | <b>5a. CONTRACT NUMBER</b>                            |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |             |                                           |                                   | <b>5b. GRANT NUMBER</b><br>F49620-99-1-0259-01-1-0259 |                                                                    |
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| <b>6. AUTHOR(S)</b><br>Alex K-Y. Jen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                           |                                   | <b>5d. PROJECT NUMBER</b>                             |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |             |                                           |                                   | <b>5e. TASK NUMBER</b>                                |                                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |             |                                           |                                   | <b>5f. WORK UNIT NUMBER</b>                           |                                                                    |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br><br>University of Washington<br>Department of Materials Science & Engineering, University of Washington<br>Seattle, WA 98195                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                                           |                                   | <b>8. PERFORMING ORGANIZATION REPORT</b>              |                                                                    |
| <b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br><br>Dr. Charles Y-C. Lee<br>AFOSR/NL<br>4015 Wilson Blvd. Room #713<br>Arlington, VA 22203-1954                                                                                                                                                                                                                                                                                                                                                                                                                                                          |             |                                           |                                   | <b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>               |                                                                    |
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| <b>13. SUPPLEMENTARY NOTES</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |             |                                           |                                   |                                                       |                                                                    |
| <b>14. ABSTRACT</b><br><br>The objective of this DURIP program is to develop an integrated instrumentation package that combines the capability of performing accurate and complete materials evaluation and shortening the time required to make critical characterization information available to device engineers and DoD program managers. The facility established in this program is capable of efficiently and systematically characterizing electrical and optical properties of organic conjugated oligomers and polymers for LEDs, solid state lasers, two-photon absorption, and photovoltaic cell applications. |             |                                           |                                   |                                                       |                                                                    |
| <b>15. SUBJECT TERMS</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |             |                                           |                                   |                                                       |                                                                    |
| <b>16. SECURITY CLASSIFICATION OF:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |             |                                           | <b>17. LIMITATION OF ABSTRACT</b> | <b>18. NUMBER OF PAGES</b><br><br>10                  | <b>19a. NAME OF RESPONSIBLE</b>                                    |
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AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

END-OF-THE-YEAR-REPORT

for

**GRANT #, F49620-01-1-0259**

**Instrumentation Facility for the Evaluation of Photonic and  
Opto-electronic Materials**

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November 20, 2002

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## 1. Introduction

Organic materials and hybrid organic/inorganic materials have the potential to play key roles in modern technology related to American defense and civilian economy. In particular, they have the potential for being the materials of choice for applications ranging from integrated optical circuits to sensor protection to display technology. In the area of integrated optical circuits (critical for the insertion of photonic technology into advanced systems), organic polymeric materials can be used for low-loss passive and infrared waveguides, electro-optic switches and high speed modulators, and integrated optical components such as wavelength filters, channel dropping filters, and power combiners. Furthermore, organic conjugated molecules and polymers can be used to fabricate highly efficient, full color displays and optically-pumped lasers utilizing the broad spectral range of emission colors available from these materials. Inherent to these applications is the ease of fabricating complex waveguide circuits or pixels over relatively large areas; the ability to build devices on almost any substrate including pre-processed semiconductor electronics; and the relatively wide range of materials properties (index of refraction, electrical conductivity, etc.) that are available or can be engineered into compatible systems. Moreover, organic materials are readily adaptable to nanoscale architectures which can, in turn, be used to enhance device response such as optical limiting. For example, amplification of inherent material optical limiting and lasing through dendrimer, block copolymers, and photonic bandgap architectures may permit critical reduction in the threshold for limiting and lasing, permitting wide scale implementation of new technology.

The first electrically pumped organic diode laser was achieved at the Bell Laboratories [Batlogg & co-workers, *Science*, **289**, 599-601 (2000)]. The threshold and other lasing characteristics of the organic diode lasers made from single-crystal thin films of pentacene were found to be comparable or superior to the best current inorganic semiconductor lasers. These initial results suggest the great potential in developing low power solid state light sources from high quality organic materials and nanostructures. Because pentacene and related polyacenes are very sensitive to oxygen and ambient moisture, development of other more stable conjugated oligomers or polymers will be essential to make organic diode lasers practical.

To realize this goal, the greatest challenge for scientists in this field is to find suitable electroluminescent (EL) material systems (light emitter, electron and hole transporters) which possess efficient and balanced charge injection/transport to ensure low operating voltages and high quantum efficiencies. In addition, they need to sustain high transient current densities ( $10^3$  A/cm<sup>2</sup>) for electrical pumping and have good mechanical properties for multi-layer integration. Furthermore, it is essential not only to minimize excited-state absorption so as to enhance optical gain but also to improve the design of lasers with either a high-Q resonant cavity or a waveguiding structure to reduce the lasing threshold. To date, many studies have been performed on optimizing one or several of the required properties. However, no single polymer has met the requirements necessary for electrically-pumped lasing.

In principle, an EL polymer requires the injection of holes and electrons into the emitter layer. The recombination of the injected electrons and holes in the polymer layer generates singlet excitons whose radiative decay produces visible light. The characteristics of an EL polymer are determined by the tunneling of both holes and electrons through the interface barriers which is caused by the band offset between the electroluminescent polymer and the

electrodes. A significant difference in the barrier height at the polymer/cathode and polymer/anode interfaces results in unbalanced hole and electron injections and therefore dramatically reduces the photon/electron quantum efficiency of the devices. In order to achieve higher device efficiency, highly luminescent polymers must be chosen, ultimate control of the metal-on-polymer interface, and balanced charge (hole and electron) injection are all considered to be crucial.

Although different groups are developing the basic luminescent molecules, polymeric materials, processes, and devices, they measure and report their results based on different specific and individual tests. Due to the different test procedures and measurement methods, it is difficult to make comparisons between the materials. Thus, selecting the most promising development path becomes difficult. To speed up the tedious selection process, it is highly desirable to have an integrated instrumentation that provides the necessary information such as charge mobility, brightness, linear and circular polarized photo- and electro-luminescence emissions, light polarization, current-electric field characteristics, and thresholds of optically pumped lasing, in a short time span. In addition, information and structure/property relationships developed during this process will be very beneficial for the material and device development for light-harvesting, light-detection, and light amplification.

## **2. Objective**

The objective of this DURIP program is to develop an integrated instrumentation package that combines the capability of performing accurate and complete materials evaluation and shortening the time required to make critical characterization information available to device engineers and DoD program managers. The facility established in this program is capable of efficiently and systematically characterizing electrical and optical properties of organic conjugated oligomers and polymers for LEDs, solid state lasers, two-photon absorption, and photovoltaic cell applications. It combines the capability of performing the measurements of charge mobility, conductivity, linear and circular polarized photo- and electro-luminescence emission spectra, luminous efficiencies, the thresholds of gain narrowing from optical pumping, as well as cross-section for two-photon absorbing chromophores. In addition, the instrumentation interfaces very well with the existing facility for performing LED and electro-optic materials research at UW. This laboratory consolidates capabilities which we have developed and which are currently being heavily used by researchers at DoD laboratories and by industry (as well as by academic researchers from a number of universities) and will assure the cost effective operation of the facility. The development of a complete material system for the above applications will demonstrate the usefulness of the procedure and instrumentation.

## **3. Impact to the new research programs on organic electronics and photovoltaic materials at University of Washington**

The established instrumentation facility greatly enhances the quality and capability of the LED/plastic laser and photovoltaic material research programs at the University of Washington (UW) to evaluate suitable material system properties. The research programs established by Professors Alex Jen and Larry Dalton possess the capability of synthesizing, characterizing, and fine-tuning the properties of novel functional polymers. Recent exciting results from the LED

material development at Professor Jen's group have shown excellent light-emitting and charge-transporting properties. Polymers with very low turn-on voltages (as low as 2.2 V), extremely high external quantum efficiencies ( $> 6\%$ ), luminous efficiency (25 lm/W at 100 cd/m<sup>2</sup>), and high brightness ( $> 60,000$  cd/m<sup>2</sup>) have been achieved. The combined properties of these polymers have provided a great material foundation for the development of highly efficient LEDs, plastic lasers, and photovoltaic cells.

UW's current facility possesses the capability of measuring conductivity and electro-activity (such as redox potentials/reversibility of the polymers by using cyclic voltammetry) of polymers. For polymer characterization, this facility is equipped with instruments such as FT-IR, UV-Vis-Near IR and FT-NMR for chemical structure identification; TGA and DSC for thermal analysis; GPC and HPLC for polymer dual-head thin film evaporator in dry box for evaporating metals and small organic molecules with controlled thickness; and Dektak instrument for measuring thin film thickness. In addition, UW has state-of-the-art clean room in its microfabrication laboratory that can provide the needed lithography and fabrication of photonic and opto-electronic devices. The instrumentation facility established through this program helps to guide the synthetic effort for fine-tuning the properties of polymers and establishing desirable light-emitting, lasing, and light-harvesting material system properties, and thus, directly impact the fabrication of highly efficient devices.

#### **4. Interface between the instrumentation and the existing facility for electro-optic (E-O) and light-emitting materials research at University of Washington**

This integrated instrumentation interfaces very well with the existing E-O and LED materials research facility at UW to provide strong capability for evaluating organic photonic/opto-electronic material properties. One of the new research program proposed by both professors Jen and Dalton aims at demonstrating an integrated all polymer LED/E-O device by using organic conjugated polymers as both a light source (plastic laser) and a photodetector, and using NLO polymer channel waveguides as an E-O switching device. This instrumentation greatly enhances the capability of quickly developing/screening both LED and E-O materials systems to ensure the greatest chance of success. In the area of polymer characterization, the facility at NU is equipped with the instruments such as TGA and DSC for thermal analysis; GPC and HPLC for polymer molecular weight measurement; and Dektak instrument for measuring thin film thickness. In addition, FT-IR and UV-Vis-Near IR spectrometer were used to determine the thermal stability of the E-O polymer thin films. In the areas of optical and electrical characterization, the micromanipulator device could be used to cure (up to 400 °C) and pole NLO thin films and channel waveguides; Metricon prism coupler could measure refractive index, optical loss, and thickness of polymer thin films; lock-in amplifier and the associated electronic system could measure optical and electro-optic signal generated by LED/E-O materials. This integrated instrumentation facility helps to bridge between the effort of evaluating E-O and LED polymeric material system properties, and thus, directly impacts the fabrication of all polymer laser devices.

#### **5. Research training of students**

The highly interdisciplinary nature of this program in developing high-performance light-emitting materials for LED/laser device applications, the outstanding faculty and institutions

involved, and connections with high technology device companies and DoD laboratories ensure a rich educational environment for the graduate students, postdoctors, and undergraduate students involved. Students are active members involved in closely integrated material synthesis, characterization, and device fabrication. Students associated with this program will emerge with a unique background and complement of skills. The ability to communicate with and work with academic, government, and industrial researchers in other disciplines towards a common goal will uniquely qualify them for the technical workforce of the future.

#### 6. Papers published that acknowledge the AFOSR

1. "Highly Efficient and Thermally Stable Nonlinear Optical Dendrimer for Electro-optics", H. Ma, B. Chen, T. Sassa, L. R. Dalton, and A. K-Y. Jen, J. Am. Chem. Soc., **2001**, *123*, 986.
2. "A Novel Bipolar Electroluminescent Poly (aryleneethynylene) Consisting of Carbazole and Diethynylthiophene units", X. Zhan, Y. Liu, D. Zhu, X. Jiang, and A. K-Y. Jen, Macromolecular Chem. Phys., **2001**, *202*, 2341.
3. "Synthesis and Characterization of Processible Electroluminescent Poly [(2,7-Fluorenyl eneethynylene)-alt-co-(2,5-Thienyleneethynylene)", X. Zhan, Y. Liu, D. Zhu, X. Jiang, A. K-Y. Jen, Synth. Metals., **2001**, *124*, 323.
4. "Synthesis and Characterization of Quinoline-Based Copolymers for Light Emitting Diodes", Y. Liu, H. Ma, and A. K-Y. Jen, J. Mater. Chem., **2001**, *11*, 1800.
5. "Functional Dendrimers for Nonlinear Optics", H. Ma and A. K-Y. Jen, Adv. Mater., **2001**, *13(15)*, 1201.
6. "Dispersion of the First Molecular Hyperpolarizability of Charge-Transfer Chromophores Studied by Hyper-Rayleigh Scattering", J. N. Woodward, C. H. Wang, and A. K-Y. Jen, Chemical Physics, **2001**, *271*, 137.
7. "A Binaphthyl-Bithiophene Copolymer for Light-Emitting Devices", Y. Liu, A. K-Y. Jen, G. Yu, Q. Hu, and L. Pu,, Macromolecular Chemistry and Physics, **2002**, *203*, 37.
8. "Photostability of Electro-optic Polymers Possessing Chromophores with Very Efficient Amino Donors and Cyano-containing Acceptors", A. Galvan-Gonzalez, G. Stegeman, A. K-Y. Jen, X. Wu, M. Canva, A.C. Kowalczyk, X. Q. Zhang, and H. S. Lackritz, J. Opt. Soc. Am. B., **2001**, *18(12)*, 1846.
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10. "Efficient Emission from an Europium Complex Containing Dendron-substituted Diketone Ligands", X. Jiang, A. K-Y. Jen, G. D. Phelan, D. Huang, T. M. Londegan, L. R. Dalton, Thin Solid Films., **2002**, *416*, 212.
11. "The Effect of Ligand Conjugation Length on Europium Complex Performance in Light-Emitting Diodes", X. Jiang, A. K-Y. Jen, D. Huang, T. M. Londegan, G. D. Phelan, L. R. Dalton, Synthetic Metals, **2002**, *125*, 331..
12. "High-Performance Exciplex Emission from Polymer Light-Emitting Diodes Based on Hole-Transporting Amine Derivatives and Electron-Transporting Polyfluorenes", X. Jiang, M. S. Liu, and A. K-Y. Jen, J. Appl. Phys., **2002**, *91(12)*, 10147.
13. "Efficient Cyano-containing Electron-Transporting Polymers for Light-Emitting Diodes", M. S. Liu, X. Jiang, P. Herguth and A. K-Y. Jen, Chem. Mater., **2001**, *13*, 3820.



14. "Highly Efficient and Thermally Stable Organic/Polymeric Electro-optic Materials by Dendritic Approach", A. K-Y. Jen, H. Ma, T. Sassa, S. Liu, S. Suresh, L. R. Dalton, and M. Haller, Proc. SPIE, **2001**, 4461, 24,
15. "Effect of Cyano-Substituents on Electron Affinity and Electron-Transporting Properties of Conjugated Polymers", M. S. Liu, X. Jiang, S. Liu, P. Herguth, and A. K-Y. Jen, Macromolecules, **2002**, 35, 3532.
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20. "Perfluorocyclobutane-Based Arylamine Hole-Transporting Materials for Organic and Polymer Light-Emitting Diodes", X. Jiang, S. Liu, M. S. Liu, P. Herguth, A. K-Y. Jen, H. Fong and M. Sarikaya, Adv. Func. Mater., **2002**, 12(11-12), 745.
21. "Design, Synthesis, and Properties of Highly Efficient Side-chain Dendronized Nonlinear Optical Polymers for Electro-optics", J. Luo, S. Liu, M. Haller, L. Liu, H. Ma, Alex K-Y. Jen, Adv. Mater., **2002**, 14(23), 1763.
22. "Red Emitting Electroluminescent Devices Based on Osmium Complexes Doped Blend of Poly(vinylnaphthalene) and 1,3,4-Oxadiazole derivative", X. Jiang, A. K-Y. Jen, B. Carlson and L. R. Dalton, Appl. Phys. Lett., **2002**, 81(17), 3125..
23. "Polymer-Based Optical Waveguides: Materials, Process, and Devices", H. Ma, A. K-Y. Jen, and L. R. Dalton, Adv. Mater., **2002**, 14(19), 1339..

#### Budget:

##### Z-scan Measurements

| EQUIPMENTS                       | MODEL                  | UNIT PRICE       | TOTALS  | VENDER AND ADDRESS                                                                                                                       |
|----------------------------------|------------------------|------------------|---------|------------------------------------------------------------------------------------------------------------------------------------------|
| Translation Stage Driver         | UTM50Pp1HL<br>25792-01 | \$3,046<br>\$600 |         | Newport Corporation<br>Attn: Order Entry<br>Department P.O. Box<br>19607 Irvine, CA 92713-9607<br>Tel: 800-222-6440<br>Fax: 949-253-1680 |
| subtotal                         |                        |                  | \$3,646 |                                                                                                                                          |
| Photo Detector<br>Photo Detector | 818-BB-22<br>818-BB-22 | \$389<br>\$389   |         | Newport Corporation<br>Attn: Order Entry<br>Department P.O. Box<br>19607 Irvine, CA 92713-9607<br>Tel: 800-222-6440<br>Fax: 949-253-1680 |
| subtotal                         |                        |                  | \$778   |                                                                                                                                          |

|                                                            |                                                 |          |                 |                                                                                                                                          |
|------------------------------------------------------------|-------------------------------------------------|----------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Beam Expander                                              | T81-3X                                          | \$475    |                 | Newport Corporation<br>Attn: Order Entry<br>Department P.O. Box<br>19607 Irvine, CA 92713-9607<br>Tel: 800-222-6440<br>Fax: 949-253-1680 |
| subtotal                                                   |                                                 |          | \$475           |                                                                                                                                          |
| Dimension CL,<br>X-Y Closed-loop<br>SPM Microscope<br>Head | DAFMCL                                          | \$40,000 | \$40,000        | Veeco Metrology Group<br>112 Robin Hill Road<br>Santa Barbara, CA 93117<br>Tel: 805-967-1400<br>Fax: 800-873-9750                        |
| subtotal                                                   |                                                 |          |                 |                                                                                                                                          |
| Autocorrelator                                             | FR-103MN                                        |          |                 | Femtochrome Research<br>2123 4th St. Berkley, CA<br>94710<br>Tel: 510-644-1869<br>Fax: 510-644-0118                                      |
| subtotal                                                   |                                                 | \$8,000  | \$8,000         |                                                                                                                                          |
| Computer                                                   | Dimension L<br>(E-VALUE CODE:<br>6V908-500815o) | \$2,168  |                 | Dell Computer<br>Corporation<br>One Dell Way Round<br>Rock, Texas 78682<br>Tel: 800-626-8286<br>Fax: 800-365-5329                        |
| subtotal                                                   |                                                 |          | \$2,168         |                                                                                                                                          |
| GPIB Controller                                            | 777158-01                                       | \$495    |                 | National Instruments<br>Corporation<br>11500 N Mopac Expwy<br>Austin, TX 78759-3504<br>Tel: 512-794-0100<br>Fax: 512-683-8411            |
| GPIB Cable                                                 | 763061-02                                       | \$85     |                 |                                                                                                                                          |
| subtotal                                                   |                                                 |          | \$580           |                                                                                                                                          |
| <b>TOTAL</b>                                               |                                                 |          | <b>\$55,647</b> |                                                                                                                                          |

#### *Mobility Measurements*

| <b>EQUIPMENT</b>                | <b>MODEL</b> | <b>UNIT PRICE</b> | <b>TOTALS</b> | <b>VENDER AND ADRESS</b>                                                                                |
|---------------------------------|--------------|-------------------|---------------|---------------------------------------------------------------------------------------------------------|
| Nitrogen Laser                  | VSL-337      | \$4,570           |               | Laser Science, Inc.<br>8E Forge Parkway<br>Franklin, MA 02038<br>Tel: 508-553-2353<br>Fax: 508-553-2355 |
| subtotal                        |              |                   | \$4,570       |                                                                                                         |
| High Voltage DC<br>Power Supply | PS350        | \$1,250           |               | Stanford Research<br>Systemes                                                                           |
| GPIB Interface                  | Option 01    | \$495             |               | 1290-D Reamwood Ave.<br>Sunnyvale, CA 94089                                                             |
| SHV to MHV<br>cable, 10'        | Option 03B   | \$50              |               | Tel: 408-744-9040<br>Fax: 408-744-9049                                                                  |
| subtotal                        |              |                   | \$1,795       |                                                                                                         |
| DC Voltage<br>Amplifier         | 353A         | \$525             |               | 126 Baywood Ave.<br>Longwood, FL 32750-3426                                                             |
| subtotal                        |              |                   | \$525         | Tel: 407-339-4355<br>Fax: 407-834-3806                                                                  |



|                                             |                                                     |                    |                 |                                                                                                                               |
|---------------------------------------------|-----------------------------------------------------|--------------------|-----------------|-------------------------------------------------------------------------------------------------------------------------------|
| Power Supply for<br>DC Voltage<br>Amplifier | C7169                                               | \$1,231            |                 | 360 Foothill Road<br>Bridgewater, NJ 08807-<br>0910<br>Tel: 908-231-0960<br>Fax: 908-231-1218                                 |
| subtotal                                    |                                                     |                    | \$1,231         |                                                                                                                               |
| Oscilloscope                                | TDS684C                                             | \$23,620           |                 | Tektronix, Inc.<br>27 Technology Drive Suite<br>Irvine, CA 92618<br>Tel: 949-789-7200<br>Fax: 949-789-1366                    |
| subtotal                                    |                                                     |                    | \$23,620        |                                                                                                                               |
| Power Meter<br>Sensor Head                  | 33-0498<br>33-1140                                  | \$1,495<br>\$1,850 |                 | COHERENT<br>2303 Lindbergh St.<br>Auburn, CA 95602<br>Tel: 530-889-5365<br>Fax: 530-889-5366                                  |
| subtotal                                    |                                                     |                    | \$3,345         |                                                                                                                               |
| Computer                                    | Inspiron C500SV<br>(E-VALUE CODE:<br>6V915-800813o) | \$1,399            |                 | Dell Computer<br>Corporation<br>One Dell Way Round<br>Rock, Texas 78682<br>Tel: 800-626-8286<br>Fax: 800-365-5329             |
| subtotal                                    |                                                     |                    | \$1,399         |                                                                                                                               |
| Gold Wire<br>99.9985%                       | 10965                                               | \$538              | \$538           | Alfa Aesar<br>30 Bond St. Ward Hill<br>MA 01835-8099<br>Tel: (800) 343-0660                                                   |
| GPIB Controller<br>GPIB Cable               | 777156-04<br>763061-02                              | \$600<br>\$85      |                 | National Instruments<br>Corporation<br>11500 N Mopac Expwy<br>Austin, TX 78759-3504<br>Tel: 512-794-0100<br>Fax: 512-683-8411 |
| Subtotal                                    |                                                     |                    | \$685           |                                                                                                                               |
| <b>TOTAL</b>                                |                                                     |                    | <b>\$37,708</b> |                                                                                                                               |

#### Photovoltaic Measurements

| EQUIPMENTS                                                                                                                   | MODEL                          | UNIT PRICE                            | TOTALS  | VENDER AND<br>ADDRESS                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------|--------------------------------|---------------------------------------|---------|----------------------------------------------------------------------------------------------------------------|
| Complete<br>Calibrated<br>Sources                                                                                            | 63375                          | \$3,124                               |         | Oriel Corporation<br>250 Long Beach Blvd.<br>Stanford, CT 06497-0872<br>Tel: 203-377-8282<br>Fax: 203-378-2457 |
| subtotal                                                                                                                     |                                |                                       | \$3,124 |                                                                                                                |
| Spectroradiome<br>ter<br>Software<br>DC power<br>supply<br>Extra Battery<br>(already<br>included with<br>standard<br>system) | PR-650<br>SpectraWin<br>DC-600 | \$11,900<br>\$1,900<br>\$245<br>\$195 |         | Photo Research, Inc.<br>9731 Topanga Canyon<br>Place<br>Chatsworth, CA 91311-<br>4135<br>Phone: (818) 341-5151 |

|                                                            |                 |         |                 |                                                                                                                    |
|------------------------------------------------------------|-----------------|---------|-----------------|--------------------------------------------------------------------------------------------------------------------|
| subtotal                                                   |                 |         | \$14,240        |                                                                                                                    |
| Extender Electronics Module (Phase imaging module for AFM) | PHAS-R          | \$9,000 |                 | Digital Instruments/Veeco Metrology Group<br>112 Robin Hill Rd.<br>Santa Barbara CA 93117<br>Phone: (800) 873-9750 |
| subtotal                                                   |                 |         | \$9,000         |                                                                                                                    |
| Xenon Arc Lamp Power Supply                                | 68811           | \$2,412 |                 | Oriol Instruments<br>250 Long Beach Blvd.<br>Stratford, CT 06497-0872<br>Tel: (203)377-8282                        |
| 400 W Xenon Arc Lamp                                       | 6260            | \$545   |                 |                                                                                                                    |
| 250 W QTH lamp                                             | 6334            | \$23    |                 |                                                                                                                    |
| Socket Adapter for QTH                                     | 66143           | \$181   |                 |                                                                                                                    |
| Housing for 200-500 W lamps                                | 66068           | \$3,953 |                 |                                                                                                                    |
| Stand alone ignitor                                        | 68706 universal | \$649   | \$7,763         |                                                                                                                    |
| <b>TOTAL</b>                                               |                 |         | <b>\$34,127</b> |                                                                                                                    |

#### Thermal Analysis

| EQUIPMENT                                  | MODEL      | UNIT PRICE | TOTALS          | VENDER and ADDRESS                                                                |
|--------------------------------------------|------------|------------|-----------------|-----------------------------------------------------------------------------------|
| DSC 2010 Differential Scanning Calorimetry | 911300.901 | \$19,000   | \$19,000        | TA Instruments<br>109 Lukens Drive<br>New Castle, DE 19720<br>Tel: (302) 427-4048 |
| Quench Cooling Acces.                      | 900674.901 | \$ 1,000   | \$ 1,000        |                                                                                   |
| DSC Sample Press                           | 900680.902 | \$ 2,400   | \$ 2,400        |                                                                                   |
| Calibrated Flow Meter                      | 270134.001 | \$ 400     | \$ 400          |                                                                                   |
| HP Printer                                 | 925003.901 | \$ 495     | \$ 495          |                                                                                   |
| Thermal Analyst 5000                       | 924500.901 | \$12,900   | \$12,900        |                                                                                   |
| TGA 2050 Thermogravimetric Analyzer        | 952400.901 | \$31,000   | \$31,000        |                                                                                   |
| <b>Total</b>                               |            |            | <b>\$67,195</b> |                                                                                   |

| (Circular Polarization of Luminescence Spectroscopy) |       |            |          |                                                   |
|------------------------------------------------------|-------|------------|----------|---------------------------------------------------|
| EQUIPMENT                                            | MODEL | UNIT PRICE | TOTAL    | VENDER AND ADDRESS                                |
| Time Interval Counter                                | SR620 | \$ 4,950   | \$ 4,950 | Stanford research Systems<br>1290-D Reamwood Ave. |
| Lock In                                              | SR830 | \$ 3,950   | \$ 3,950 |                                                   |
|                                                      | SR560 | \$ 1,995   | \$ 1,995 |                                                   |

|                                                                                                                                                           |                                                                                 |                                                             |                                                                                    |                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Amplifier<br>Preamplifier<br><b>Subtotal</b>                                                                                                              |                                                                                 |                                                             | <b>\$10,895</b>                                                                    | Sunnyvale, CA 94089<br>Phone: (408) 744-9040<br>Fax: (408) 744-9049                                                             |
| Photoelastic<br>Modulator<br>(Modulator,<br>driver and<br>GPIB)<br><b>Subtotal</b>                                                                        | I/FS50                                                                          | \$ 2,695<br>\$ 1,895<br>\$ 95                               | \$ 2,695<br>\$1,895<br>\$ 950<br><b>\$4,685</b>                                    | Hinds instruments, Inc.<br>3175 N. W. Alcock Dr.<br>Hillsboro, OR 97124<br>Phone: (503) 690-2000<br>Fax: (503) 690-3000         |
| Monochromator<br>Grating<br><br>Fiber Coupler<br>Fiber Cable<br><br>GPIB<br><b>Subtotal</b>                                                               | CM 110<br>AG1200-00600-<br>303<br>AF332<br>AF200-0200 FC<br>/FC-U20s<br>CM-GPIB | \$ 1,985<br><br>\$ 200<br>\$ 320<br><br>\$ 200<br>\$ 750    | \$ 1,985<br><br>\$ 200<br>\$ 320<br><br>\$ 200<br>\$ 750<br><b>\$ 3,255</b>        | CVI Laser Corporation<br>Livermore, CA<br>Tel: (925) 449-1064<br>Fax: (925) 294-7747                                            |
| Glan Polarizing<br>Prisms (x2)<br>Polarizer<br>Holder (x2)<br>Polarizer<br>Holder<br>Quartz<br>Retardation<br>Plate<br><b>Subtotal</b>                    | 03 PTA 003<br>07 HPP 004<br>07 HPR 511<br>02 WRQ 005                            | \$ 750<br>\$ 65<br>\$ 69<br>\$ 375                          | \$ 750<br>\$ 130<br>\$ 69<br>\$ 375<br><br><b>\$1,324</b>                          | Melles Griot<br>1770 Kettering Street<br>Irvine, CA 92614<br>Phone: (714) 261-5600<br>Fax: (714) 261-7790                       |
| PMT<br>Power Supply<br>Adapter<br><br><b>Subtotal</b>                                                                                                     | H7155-21<br>C7169<br>E5776                                                      | \$ 1,291<br>\$ 1,231<br>\$ 73.92                            | \$ 1,291<br>\$ 1,231<br>\$ 74<br><br><b>\$ 2,596</b>                               | Hamamatsu Corporation<br>360 FootHill Road<br>Bridgewater, NJ 08807<br>Tel: (908) 231-0960<br>Fax: (908) 231-1218               |
| Sample<br>Compartment<br>Spectrophotome<br>ter Cell (x2)<br>1000 W Xenon<br>arc lamp<br>Socket Adapter<br>Lamp Housing<br>Power Supply<br><b>Subtotal</b> | 78100<br>13960<br>6269<br>6162<br>66021<br>68820                                | \$ 772<br>\$ 198<br>\$ 619<br>\$ 72<br>\$ 2,850<br>\$ 3,604 | \$ 772<br>\$ 396<br>\$ 619<br>\$ 72<br>\$ 2,850<br>\$ 3,604<br><br><b>\$ 8,313</b> | Oriel Corporation<br>250 longbeach Blvd.,<br>P. O. Box 872<br>Stratford, CT 06497<br>Tel: (203) 377-8282<br>Fax: (203) 378-2457 |
| Optical Top<br>Vibration<br>Isolation<br>System<br>Complete Shelf<br>system<br><br><b>Subtotal</b>                                                        | 784-659-02R<br>14-416-36<br>81-233-01                                           | \$ 5,520<br>\$ 2,740<br>\$ 1,180                            | \$ 5,520<br>\$ 2,740<br>\$ 1,180<br><br><b>\$ 9,440</b>                            | Technical Manufacturing<br>Corp.<br>15 Centennial Drive<br>Peabody, MA 01960<br>Tel: (978) 532-6330<br>Fax: (978) 531           |
| Balance (AX12)                                                                                                                                            | 321-60181-13                                                                    | \$ 1,830                                                    | \$1,830                                                                            | Shimadzu Scientific<br>Instruments<br>7060 Koll Center<br>Parking Suite 328<br>Pleasanton, CA 94566                             |

|                                  |                                                     |                 |                 |                                                                                                                              |
|----------------------------------|-----------------------------------------------------|-----------------|-----------------|------------------------------------------------------------------------------------------------------------------------------|
| <b>Subtotal</b>                  |                                                     |                 | <b>\$ 1,830</b> | Phone: 1-800-482-0253<br>Fax: 925-462-7348                                                                                   |
| Computer<br>(control)            | Dimension L<br>(E-VALUE<br>CODE: 6V908-<br>500815o) | \$ 2,168        | \$ 2,168        | Dell Computer<br>Corporation<br>One Dell Way<br>Round Rock, TX 78682<br>Tel: 800-626-8286<br>Fax: 800-365-5329               |
| <b>Subtotal</b>                  |                                                     |                 | <b>\$ 2,168</b> |                                                                                                                              |
| GPIB<br>Controller<br>GPIB Cable | 777158-01<br>763061-02                              | \$ 495<br>\$ 85 | \$ 495<br>\$ 85 | National Instruments<br>Corporation<br>11500 N Mopac Expwy<br>Austin, TX 78759<br>Tel: (512) 794-0100<br>Tel: (512) 683-8411 |
| <b>Subtotal</b>                  |                                                     |                 | <b>\$580</b>    |                                                                                                                              |
| <b>Total</b>                     |                                                     |                 | <b>\$45,086</b> |                                                                                                                              |

**Grant Total Budget: \$ 239,763**